Digital Return Path for Hybrid Fiber/Coax Network

Technical Field of the Invention

The present invention relates generally to the field of telecommunications and, in particular, to a digital return path for a hybrid fiber/coax network.

Background

Cable networks originally carried programming from an head end to subscribers over a network of coaxial cable. Over time, these networks have changed. Some cable networks now include fiber optic links as part of the network. This variety of cable network is colloquially referred to as an "hybrid fiber/coax" network.

An hybrid fiber/coax network typically includes an head end that broadcasts programming over the network to subscribers in a downstream direction. The network includes two main portions. The first portion of the network is optical links that connect the head end with a number of geographically dispersed distribution nodes. These nodes are referred to as "optical distribution nodes" or "ODNs." At the ODNs, signals from the head end that carry the programming are converted from optical signals to electrical signals. The second portion of the network is coaxial links that connect the ODNs with subscriber equipment. The electrical signals are transmitted to the subscriber equipment over the coaxial cable links.

In recent years, the cable industry has experimented with systems that allow for bi-directional communication between subscriber equipment and the head end. This would allow for services such as video-on-demand, telephony and Internet traffic to be offered over a cable network. The upstream communication is typically reserved for transmission in the 5 to 42 MHZ frequency range.

One problem with such as system is the quality of signals that are transmitted over this return path from the subscriber equipment to the head end. The signals are subject to problems such as distortion and noise. Further, it is difficult to measure the effect of these influences on the signals.

For the reasons stated above, and for other reasons stated below which will become apparent to those skilled in the art upon reading and understanding the present specification, there is a need in the art for an improved return path for a hybrid fiber/coax network.

Summary

The above mentioned problems with telecommunications systems and other problems are addressed by the present invention and will be understood by reading and studying the following specification. A hybrid fiber/coax network is described which uses digital, baseband transmission in the reverse link between the optical distribution node and the head end.

Brief Description of the Drawings

Figure 1 is a block diagram of an embodiment of a hybrid fiber/coax network constructed according to the teachings of the present invention.

Figure 2 is a block diagram of one embodiment of a transmitter in an optical distribution node for a return path of a hybrid fiber/coax network according to the teachings of the present invention.

Figure 3 is a block diagram of one embodiment of a receiver in a head end for a return path of a hybrid fiber/coax network according to the teachings of the present invention.

Figure 4 is a block diagram of another embodiment of a transmitter in an optical distribution node for a return path of a hybrid fiber/coax network according to the teachings of the present invention.

Figure 5 is a block diagram of another embodiment of a receiver in a head end for a return path of a hybrid fiber/coax network according to the teachings of the present invention.

Detailed Description

The following detailed description refers to the accompanying drawings which form a part of the specification. The drawings show, and the detailed description describes, by way of illustration specific illustrative embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. Other embodiments may be used and logical, mechanical and electrical changes may be made without departing from the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense.

I. Hybrid Fiber/Coax Network with Digital Return Path

Figure 1 is a block diagram of an embodiment of a hybrid fiber/coax network, indicated generally at 100, and constructed according to the teachings of the present invention. Network 100 is a bi-directional network that carries signals between head end 102 and a number of users.

For simplicity in describing network 100, the users are represented in Figure 1 by subscriber equipment 104. It is understood that network 100 can serve any appropriate number of users. Further, network 100 can support a wide variety of subscriber equipment including, but not limited to, audio/video, data, and telephony equipment.

Head end 102 is coupled to subscriber equipment 104 over a combination of fiber optics and coaxial cable. Namely, head end 102 is coupled via fiber optic link 105 with optical distribution node 106. Optical distribution node 106 is also coupled to coaxial cable links or branches 108. Typically, optical distribution node 106 supports up to four coaxial links 108. However, any appropriate number of links can be used to carry signals between optical distribution node 106 and subscriber equipment 104 through the use of multiple output broadband amplifiers 111 or splitters 109.

Subscriber equipment, represented by subscriber equipment 104, is selectively coupled to coaxial links 108 via taps 110.

Advantageously, network 100 uses baseband digital transmission to carry upstream signals from optical distribution node 106 to head end 102 optical fiber link 105. Typically, these upstream transmissions are accomplished in the 5 to 42 MHZ band. However, other transmission formats can be used to carry the upstream transmissions in network 100. At optical distribution node 106, the upstream frequency band is converted from an analog signal to a baseband, digital signal by an upstream transmitter. Exemplary embodiments of a transmitter for optical distribution node 106 are shown and described with respect to Figures 2 and 4.

Additional data may also be added to the digital signal, e.g., signals that monitor the status of the optical distribution node, the bit error rate link performance monitor. This digital signal is then transmitted over optical link 105 to a receiver at head end 102 that converts the digital signal back to analog form for processing by the head end.

The use of baseband, digital transmission in the upstream over optical link 105 provides several advantages over traditional analog transmission. For example, the performance of the return path over link 105 can be monitored in real time. This provides, among other advantages, the opportunity to for real-time analysis of data integrity, e.g., monitoring bit error rate link performance monitoring. Further, the field set-up of the optical distribution node is simplified over conventional approaches since issues related to, for example, complex balancing of tilt, level and average power in analog equipment to achieve optimum analog laser performance have been removed.

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II. Transmitter for Digital Return Path

Figure 2 is a block diagram of an embodiment of a transmitter, indicated generally at 200, in an optical distribution node for a return path of a hybrid fiber/coax network according to the teachings of the present invention. Transmitter 200 includes bandpass filter 202 coupled to receive input from 1 to 4 coaxial links. Typically, signals from four coaxial links are coupled to bandpass filter 202 through 4 to 1 combiner 201. Each coaxial input to combiner 201 shares the same frequency spectrum. In one embodiment, bandpass filter 202 selectively passes signals in the 5 to 42 MHZ frequency range. The analog signals from bandpass filter 202 are provided to analog to

digital converter (ADC) 204 to convert the signals to baseband digital signals. The output of ADC 204 is an n bit wide signal, e.g., 10 bits. ADC 204 samples the analog signal from the coaxial links and produces 850 to 1000 Mega-bits per second with a 10 bit wide ADC 204. An analog to digital converter that operates at this rate is AD9070, commercially available from Analog Devices, of Norwood, MA. The digital output of ADC 204 is converted to a serial data stream by multiplexer (MUX) 210.

MUX 210 also can add other data to the serial data stream. For example, status information from status monitor 206 can be added. Status monitor 206 provides information on the operation of the optical distribution node to the head end of the hybrid fiber/coax network. Further, other data 208 can also be provided. This data includes framing data and data for bit error rate link performance testing.

MUX 204 is coupled to optical transmitter 214 through laser drive amplifier 212. Optical transmitter comprises, for example, a 1310 nanometer, digital laser that transmits data with a bit rate of up to approximately 1 Gigabits per second. This bit rate is approximately a SONET OC-24 bit rate. A digital laser that operates in this manner is part no. 1241FCDC, commercially available from Lucent Technology of Murray Hill, NJ. Other digital lasers can also be used that operate at different wavelengths, e.g., 1550 nanometers, and with different data rates.

Optical transmitter 214 provides this optical signal to a head end over an optical fiber.

III. Receiver for Digital Return Path

Figure 3 is a block diagram of one embodiment of a receiver, indicated generally at 300, in a head end for a baseband, digital return path of a hybrid fiber/coax network according to the teachings of the present invention. Receiver 300 includes an optical receiver, e.g., avalanche photo diode, that is coupled to receive optical signals over an optical fiber from an optical distribution node. An acceptable optical receiver is the 1319P that is commercially available from Lucent Technology, of Murray Hill, NJ.

Optical receiver 302 is coupled to clock data recovery device (CDR) 306 through transimpedence amplifier 304. In one embodiment, CDR 306 is based on a

SONET OC-24 type of clock data recovery device commercially available from Lucent Technologies of Murray Hill, NJ. CDR 306 recovers the clock signal (CLK) used in transmitting the optical signals over the optical fiber. Further CDR 306 separates out the data from the received digital signal. CDR 306 maintains the data synchronous with the clock signal.

CDR 306 is coupled to provide the data and the CLK signal to decode logic 308. Decode logic 308 is coupled to demultiplexer (DMUX) 310. Decode logic 308 aligns the start of data information to DMUX 310 with respect to the framing start that is generated by other data block 208 of Figure 2. All data is position encoded with a frame. Decode logic 308 detects frame start and position by bit.

DMUX 310 separates data from the digital signal that was added to the digital data stream at the optical distribution node. For example, DMUX 310 separates out data from a status monitor and provides this information to block 314. This information can be used by the head end to control the operation, or monitor the operation of the optical distribution node. Further, DMUX 310 provides other data 208 that was added to the digital signal to other data block 312. This other data may include, for example, data for determining a bit error rate link performance or other appropriate data. Finally, DMUX 310 provides an n-bit signal to digital to analog converter (DAC) 316. This signal corresponds to the digitization of the upstream signal received by the optical distribution node. DAC 316 converts this signal to an analog signal. An appropriate DAC for this function is the AD9731 commercially available from Analog Devices, of Norwood, MA.

DAC 316 is coupled to filter 318. Filter 318 compensates for the effect of quantization in the analog to digital conversion at the optical distribution node by use of a (sin x)/x function. The output of filter 318 is analog data that is provided to the head end for processing, e.g., the output of filter 318 is an analog signal in the 5 to 42 MHZ frequency range.

IV. Alternative Embodiment for Transmitter for Digital Return Path

Figure 4 is a block diagram of another embodiment of a transmitter, indicated generally at 400, in an optical distribution node for a return path of a hybrid fiber/coax network according to the teachings of the present invention. Transmitter 400 includes bandpass filters 402a, 402b, 402c, and 402d. to receive input from four separate coaxial links. Bandpass filters 402a, 402b, 402c, and 402d pass signals in the 5 to 42 MHZ frequency range. Other frequency ranges can be used for the upstream communications.

This embodiment implements a digital form of "block conversion" such that each coaxial link can use the full 5 to 42 MHZ frequency spectrum. Conventionally, upstream transmission in a hybrid fiber/coax system is limited by the fact that each of the coaxial links coupled to a common optical distribution node uses the same frequency spectrum to carry signals from users to the head end. Thus, the coaxial links cannot make full use of the upstream spectrum without potentially interfering with each other when combined at the optical distribution node. Block conversion has been used in some systems so that the upstream communications on the coaxial legs are frequency shifted at the optical distribution node such that each coaxial link can use the full 5 to 42 MHZ frequency spectrum. This is referred to as "block conversion."

In this embodiment, the effect of block conversion is achieved with digital signals; namely, each coaxial leg can use the full upstream spectrum, e.g., 5 to 42 MHZ. When signals from the multiple coaxial links are combined at the optical distribution node. The signal from each coaxial link is separately filtered and converted to digital format. Then, the separate digital signals are combined into a higher bit rate digital signal for transmission to the head end. Thus, this embodiment accomplishes the advantages of block conversion in the digital domain.

The analog signals from bandpass filters 402a, 402b, 402c, and 402d are provided to analog to digital converters (ADCs) 404a, 404b, 404c, and 404d, respectively. ADCs 404a, 404b, 404c, and 404d convert the signals from bandpass filters 402a, 402b, 402c, and 402d, respectfully, to baseband digital signals. ADCs 404a, 404b, 404c, and 404d each provide an "n" bit wide signal, e.g., 10 bits as a digital output. ADCs 404a, 404b, 404c, and 404d each sample their respective analog signals

from the bandpass filters 402a, 402b, 402c, and 402d and produce 850 to 1000 Megabits per second with 10 bit wide ADCs 404a, 404b, 404c, and 404d. An analog to digital converter that operates at this rate is AD9070, commercially available from Analog Devices, of Norwood, MA. The digital output of ADCs 404a, 404b, 404c, and 404d are each converted to a serial data stream by multiplexers (MUXs) 410a, 410b, 410c, and 410d, respectively.

MUXs 410a, 410b, 410c, and 410d are coupled to multiplexer 411 to create a digital data stream for transmission to the head end. Additional information also can be added to the serial data stream output by multiplexer 411. For example, status information from status monitor 406 can be added. Status monitor 406 provides information on the operation of the optical distribution node to the head end of the hybrid fiber/coax network. Further, other data 408 can also be provided. This data includes, for example, framing data and data for bit error rate link performance testing.

MUX 411 is coupled to optical transmitter 414 through laser drive amplifier 412. Optical transmitter 412 comprises, for example, a 1310 nanometer, digital laser that transmits data with a bit rate of up to approximately 5 Gigabits per second. This bit rate is approximately a SONET OC-96 bit rate. A digital laser that operates in this manner is E2560, commercially available from Lucent Technologies of Murray Hill, NJ. Other digital lasers can also be used that operate at different wavelengths, e.g., 1550 nanometers, and with different data rates.

Optical transmitter 414 provides this signal to a head end over an optical fiber.

V. Alternative Embodiment for Receiver for Digital Return Path

Figure 5 is a block diagram of another embodiment of a receiver, indicated generally at 500, in a head end for a baseband digital return path of a hybrid fiber/coax network according to the teachings of the present invention. Receiver 500 includes an optical receiver, e.g., avalanche photo diode, that is coupled to receive optical signals over an optical fiber from an optical distribution node. An acceptable optical receiver is the 1319TP that is commercially available from Lucent Technology, of Murray Hill, NJ.

Receiver 500 works with signals that implement a digital form of block conversion such as described above with respect to Figure 4.

Optical receiver 502 is coupled to clock data recovery device (CDR) 506 through transimpedence amplifier 504. In one embodiment, CDR 506 is based on a SONET OC-96 type of clock data recovery device commercially available from Lucent Technologies of Murray Hill, NJ. CDR 506 recovers the clock signal (CLK) used in transmitting the optical signals over the optical fiber. Further CDR 506 separates out the data from the received digital signal. CDR 506 maintains the data synchronous with the clock signal.

CDR 506 is coupled to provide the data and the CLK signal to decode logic 508. Decode logic 508 is coupled to demultiplexer (DMUX) 509. Decode logic 508 aligns the start of data information to DMUX 509 with respect to the framing start that is generated by other data block 408 of Figure 4. All data is position encoded with a frame. Decode logic 508 detects frame start and position by bit.

DMUX 509 separates data from the digital signal that was added to the digital data stream at the optical distribution node. For example, DMUX 509 separates out data from a status monitor and provides this information to block 514. This information can be used by the head end to control the operation, or monitor the operation of the optical distribution node. Further, DMUX 509 provides other data ~~509~~ 408 that was added 3/9/99 to the digital signal to other data block 512. This other data may include, for example, data for determining a bit error rate link performance or other appropriate data. Finally, DMUX 509 separates the remaining data into a number of channels corresponding to the coaxial links that provided the data to the optical distribution node. This data is provided to demultiplexers (DMUXs) 510a, 510b, 510c, and 510d. DMUXs 510a, 510b, 510c, and 510d each provide an n-bit wide signal, e.g., 10 bits, to digital to analog converters (DACs) 516a, 516b, 516c, and 516d, respectively. These signals correspond to the digitization of the upstream signal received by the optical distribution node from each of the coaxial links. DACs 516a, 516b, 516c, and 516d each convert their respective signals to an analog signals. An appropriate DAC for this function is the AD 9731 commercially available from Analog Devices, of Norwood, MA.

DACs 516a, 516b, 516c, and 516d are coupled to filters 518a, 518b, 518c, and 518d, respectively. Filters 518a, 518b, 518c, and 518d compensate for the effect of quantization in the analog to digital conversion at the optical distribution node by use of a (sin x)/x function. The output of filters 518a, 518b, 518c, and 518d are analog data streams that are provided to the head end for processing, e.g., the output of filters 518a, 518b, 518c, and 518d are analog signals in the 5 to 42 MHZ frequency range.

Conclusion

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiment shown. This application is intended to cover any adaptations or variations of the present invention. For example, the upstream signals can be transmitted in a different frequency spectrum. Further, other wavelengths can be used to transmit the digital signals over the optical link between the optical distribution node and the head end. The optical distribution nodes can also be coupled to any appropriate number of coaxial links.